

Republic of Kenya

EDICT OF GOVERNMENT

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KS 4-1 (2003) (English): East African Standard
for Batteries for use in photovoltaic power
systems – Specification – Part 1: General
requirements (Draft Standard)



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EAST AFRICAN STANDARD

Batteries for use in photovoltaic power systems — Specification —

**Part 1:
General requirements**

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EAST AFRICAN COMMUNITY

Foreword

Development of the East African Standards has been necessitated by the need for harmonizing requirements governing quality of products and services in East Africa. It is envisaged that through harmonized standardization, trade barriers which are encountered when goods and services are exchanged within the Community will be removed.

In order to meet the above objectives, the EAC Partner States have enacted an East African Standardization, Quality Assurance, Metrology and Test Act, 2006 (EAC SQMT Act, 2006) to make provisions for ensuring standardization, quality assurance, metrology and testing of products produced or originating in a third country and traded in the Community in order to facilitate industrial development and trade as well as helping to protect the health and safety of society and the environment in the Community.

East African Standards are formulated in accordance with the procedures established by the East African Standards Committee. The East African Standards Committee is established under the provisions of Article 4 of the EAC SQMT Act, 2006. The Committee is composed of representatives of the National Standards Bodies in Partner States, together with the representatives from the private sectors and consumer organizations. Draft East African Standards are circulated to stakeholders through the National Standards Bodies in the Partner States. The comments received are discussed and incorporated before finalization of standards, in accordance with the procedures of the Community.

Article 15(1) of the EAC SQMT Act, 2006 provides that “Within six months of the declaration of an East African Standard, the Partner States shall adopt, without deviation from the approved text of the standard, the East African Standard as a national standard and withdraw any existing national standard with similar scope and purpose”.

East African Standards are subject to review, to keep pace with technological advances. Users of the East African Standards are therefore expected to ensure that they always have the latest versions of the standards they are implementing.

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Introduction

The PV system designer depends on the capacity of a storage battery for reliable extended operation of the system load during hours of darkness and below-average solar resource. Photovoltaic systems can subject batteries to harsh operational environments with minimal control of recharge profiles. The economics of photovoltaic modules limit the ability to charge the battery at more traditional motive power deep cycle charge rates and times. Typical charge rates for small PV systems are less than 6.5 amperes and may be less than 2.0 amperes per 100 ampere-hours of battery capacity. Relatively low rates, coupled with the unpredictability of the solar resource, results in limited recharge capabilities.

Standalone PV systems are typically used in remote locations with minimal power resources, which limits the amount of initial battery boost charging possible. In daily operation, the limited available PV charging source combined with relatively low-charge regulation voltages may be insufficient to provide a full charge to the battery. In an effort to identify appropriate standalone PV system parameters together with appropriate battery technology, repeatable test procedures are provided to verify PV system parameters. This test procedure is designed to be characteristic of the low-charge/discharge rates, shallow cycle operation, and various charging methods used in PV systems.

Contents

1	Scope	1
2	Normative references	1
3	Definitions	2
4	Conditions of use	4
4.1	Photovoltaic system	4
4.2	Secondary cells and batteries	4
4.3	General operating conditions	5
5	General requirements	8
5.1	General	8
5.2	Mechanical endurance	10
5.3	Marking	10
6	Functional characteristics and specific requirements	10
6.1	Capacity	10
6.2	Cycle life	11
6.3	Charge-discharge efficiency	12
6.4	Resistance to overcharge	12
6.5	Charge retention	12
6.6	Charge acceptance after deep discharge	12
6.7	Short-circuit current and internal resistance	12
6.8	Mechanical endurance	13
6.9	Maximum permissible current	13
7	Test conditions	13
7.1	Sampling and preparation of batteries for testing	13
7.2	Accuracy of measuring instruments	15
7.3	Physical examination	15
8	Test methods	16
8.1	Verification of rated capacity (20-hour discharge rate)	16
8.2	Cycle life	17
8.3	Charge retention test	18
8.4	Cycle endurance test in photovoltaic application (extreme conditions)	18
8.5	Charge acceptance after deep discharge	20
8.6	Short-circuit current and internal resistance determination	20
8.7	Mechanical endurance tests — Thermal cycling	22
8.8	Mechanical endurance tests — Bump test	22
8.9	Mechanical endurance tests — Drop test	22
8.10	Mechanical endurance tests — Vibration test	23
8.11	High rate discharge capability	23
8.12	Overcharge resistance test method	23
8.13	Content and durability of required markings	24
9	Guarantee	25
10	Marking	25
10.1	Marking on battery	25
10.2	Information to be supplied on the package	25
10.3	Marking of polarity	26
11	Recommended use of tests	26
11.1	Type test	26
11.2	Acceptance test	27
12	Safety	27
13	Documentation	27
	Annex A (informative) Ten-hour rate capacity (10 hour discharge rate)	28
	Annex B (informative) Lead-acid battery technologies	29
	Annex C (informative) Lead-acid battery characteristics	32
	Annex D (informative) PV system operational parameters	37

Batteries for use in photovoltaic power systems — Specification — Part 1: General requirements

1 Scope

This East African Standard specifies general requirements and methods of test for secondary cells and batteries used in photovoltaic power systems.

This East African Standard does not include specific information relating to battery sizing, method of charge or PV system design.

This standard provides guidance in understanding battery charging requirements in relation to the operational parameters that affect overall PV system design and battery performance. This standard will aid in battery selection, evaluation, and PV system design, and provides methods of test for evaluating the selected battery.

NOTE This standard is applicable to lead-acid and nickel-cadmium cells and batteries. It is intended to amend this standard to include other electrochemical systems when they become available.

2 Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-482, *International Electrotechnical Vocabulary (IEV) — Part 482: Primary and secondary cells and batteries*

IEC 60622, *Secondary cells and batteries containing alkaline or other non-acid electrolytes — Sealed nickel-cadmium prismatic rechargeable single cells*

IEC 60623, *Secondary cells and batteries containing alkaline or other non-acid electrolytes — Vented nickel-cadmium prismatic rechargeable single cells*

IEC 60721-1, *Classification of environmental conditions — Part 1: Environmental parameters and their severities*

IEC 60896-11, *Stationary lead-acid batteries — Part 11: Vented types — General requirements and methods of test*

IEC 60896-21, *Stationary lead-acid batteries — Part 21: Valve-regulated types — Methods of test*

IEC 61056-1, *General purpose lead-acid batteries (valve-regulated types) — Part 1: General requirements, functional characteristics — Methods of test*

IEC 62259, *Secondary cells and batteries containing alkaline or other non-acid electrolytes — Nickel cadmium prismatic secondary single cells with partial gas recombination*

CD/K/04-2:2003, *Batteries for use in photovoltaic power systems — Specification — Part 2: Modified lead acid batteries*

EAS 121, *Water for lead acid batteries — Specification*

EAS 362, *Solar photovoltaic power systems — Glossary*

KS 1783, *Rubber and plastic containers for lead-acid storage batteries — Specification*

KS 242, *Specification for sulfuric acid for use in lead-acid batteries*

EAS 122, *Sulfuric acid — Specification*

IEC 60254-1, *Lead-acid traction batteries — Part 1: General requirements and methods of tests*

3 Definitions

For purposes of this East African Standard, the definitions and terms for secondary cells and batteries given in IEC 60050-482, and those for photovoltaic generator systems given in EAS 362 in addition to those given below apply.

3.1

ampere-hour

a unit of measure for battery capacity, obtained by multiplying the current flow in amperes by the time in hours during which the current flows

3.2

ampere-hour capacity

the number of ampere-hours which a cell or battery can deliver under specified conditions, i.e. charging conditions, the rate of discharge, temperature and final voltage

3.3

ampere-hours (Ah) charge efficiency

ratio of the Ah discharged by the required Ah charged to maintain battery capacity under specific cycle and charging conditions

3.4

battery

two or more cells electrically connected, generally in series to meet the required voltage and ampere-hour capacity

3.5

battery capacity

the total number of ampere-hours that can be withdrawn from a fully charged battery at a given rate of discharge to a specified cut-off voltage

3.6

battery electrolyte

a conducting medium in the battery cell in which the flow of electric current takes place by the migration of ions

3.7

C₂₀

the rated capacity of a battery specified at a constant discharge current which will fully discharge the battery in 20 h

3.8

cell

the smallest functional unit of a battery

3.9

calculated photovoltaic (PV) array ampere-hours (Ah) to load Ah ratio (A:L)

The monthly daily average PV ampere-hours available divided by the monthly daily average load ampere-hours. Average daily PV ampere-hours are calculated by taking the daily average solar resource for each month in kWh/m² times the PV array current at its maximum power point (I_{mp}) at standard test conditions (STC). Array to load ratios can also be calculated in terms of their respective Watt-hour parameters.

3.10**Charge ampere-hours (Ah) to load Ah ratio (C:L)**

The total available charge ampere-hours (Ah) divided by the load Ah. Charge Ah are calculated by integrating the set charge current over the total charge time. The actual charge Ah is not necessarily the calculated charge Ah because of charge current tapering at regulation voltage.

3.11**charge controller**

An electrical control device that regulates battery charging by voltage control and/or other means. It may also incorporate one or more of the following functions: discharge termination, regulation voltage temperature compensation, load control, and status indication.

3.12**c/x charge/discharge rate**

the manufacturer's rated battery capacity in ampere-hours usually at the 20 h rate divided by the discharge time in hours. A 100 Ah battery discharged/charged at the 35 h rate would result in a discharge/charge current of 2.86 ampere ($100/35 = 2.86$ ampere).

3.13**deficit charge**

Charging a battery with less ampere-hours (Ah) than is required to return the battery to its initial state-of charge. This results in a reduction in the battery state-of charge.

3.14**end-of discharge voltage (EODV)**

The battery voltage just prior to load termination. It will be the minimum voltage for the given discharge cycle.

3.15**days of autonomy**

the number of days which a fully charged battery can support the load with no power received from external sources e.g. photovoltaic (PV) array

3.16**deep cycle battery**

a battery which is designed so that up to 80 % of the rated ampere-hours can be removed on a regular daily basis without damage or unduly shortening life

3.17**end-of-charge voltage**

the cell or battery voltage at which charging is normally terminated by the charging source or continued at constant voltage condition

3.18**lead-acid battery**

electrochemical storage device that includes pure lead, lead-antimony, or lead-calcium types with sulphuric acid electrolyte

3.19**rated capacity**

the full amount of energy a battery can deliver when fully charged and when discharged down to a minimum cut-off voltage under specified conditions of temperature, current and final voltage

3.20**terminal voltage**

the voltage across the terminals at any time, whether the battery is charging, discharging, or in open circuit

3.21

charging and discharging efficiency test

the efficiency test which is carried out in such a manner that the specimen in the state of full charge is discharged to the cut-off voltage of discharge, charged from this state by an ampere-hour equal to the discharged ampere-hour, then discharged again to the cut-off voltage of discharge

3.22

duty cycle

Sequence of operating conditions to which a cell or battery is subjected. This includes factors such as charge and discharge rates and conditions, depth of discharge, numbers and types of cycles, temperatures and length of time in open circuit stand.

3.23

depth of discharge

percentage of rated capacity discharged from a battery

4 Conditions of use

This clause identifies the operating conditions experienced by secondary batteries in photovoltaic applications during their use.

4.1 Photovoltaic system

The photovoltaic systems with batteries referred to in this standard can supply constant, variable or intermittent energy to the connected equipment (load). This system may include hybrid or grid-connected systems. The connected equipment may be pumps, refrigerators, lighting systems, communication systems, etc.

4.2 Secondary cells and batteries

4.2.1 Secondary cells and batteries used in photovoltaic systems are categorized as follows:

- vented (flooded);
- valve-regulated (gelled and AGM); and
- gas-tight sealed (nickel-cadmium only).

The cells and batteries shall be delivered in any one of the following conditions:

- discharged and drained (nickel-cadmium batteries only);
- charged and filled;
- dry charged and unfilled (lead-acid batteries only); and
- discharged and filled (nickel-cadmium batteries only).

4.2.2 Secondary cells and batteries shall meet the following requirements:

- a) Shall be of a design offering deep cycle capability.
- b) Shall have a low or no-maintenance requirement. Maintenance intervals in the low maintenance category shall be not less than four months in mean daily average temperatures of 25 °C and three months in mean daily temperatures of 35 °C provided that battery charge is at the current rate and voltage recommended by the manufacturer of the battery.

4.3 General operating conditions

Batteries in a typical PV system operating under average site weather conditions may be subjected to the following conditions.

4.3.1 Autonomy time

The battery is designed to supply energy under specified conditions for periods of time typically 3 days without or with minimum solar irradiation. Some systems can have significantly more or less than this time.

Autonomy for a non-essential system shall be two days, and for essential systems five days at an average daily consumption.

NOTE 1 When calculating the required battery capacity, the following items should be considered:

- required daily/seasonal cycle (there may be restrictions on the maximum depth of discharge);
- time required to access the site;
- ageing;
- temperature impact;

NOTE 2 The requirements of this clause are aimed at ensuring that suppliers take into account the requirements of the PV system that the battery is to be used.

4.3.2 Typical charge and discharge currents

The charge current generated by the photovoltaic generator and the discharge current determined by the load are shown in Table 1.

Table 1 — Charge and discharge currents

	Lead acid		Nickel cadmium	
Charge current generated by the PV generator				
Maximum charge current	I_{20}	$= C_{20}/20h$	I_{20}	$= I_t / 20$
Average charge current	I_{50}	$= C_{50}/50h$	I_{50}	$= I_t / 50$
Discharge current determined by the load				
Average discharge current	I_{120}	$= C_{120}/120h$	I_{120}	$= I_t / 120$
NOTE 1 Depending on the system design, e.g. for hybrid systems, the charge and the discharge current may vary in a wider range.				
NOTE 2 In some systems the load current must be supplied at the same time as the battery charging current.				
NOTE 3				
For lead acid	For nickel cadmium			
C_n is the rated capacity (Ah) n is the time base in hours for which the capacity is declared	C_n is the rated capacity (Ah) n is the time base in hours for which the capacity is declared			
t is the time in hours	t is the time in hours			
$I_n = C_n / t$	See IEC 61434 for the reference test current I_t $I_t = C_n \text{ (Ah) } / 1 \text{ h and } I_n = I_t / t$			

4.3.3 Daily cycle

The battery is normally exposed to a daily cycle with:

- a) charging during daylight hours;
- b) discharging during night-time hours.

A typical daily discharge can be in the range of 2 % to 20 % of the battery capacity.

4.3.4 Seasonal cycle

The battery may be exposed to a seasonal cycle of state of charge because of varying average charging conditions as follows:

- periods with low solar irradiation, for instance during overcast/cloudy days causing low energy production. The state of charge of the battery (available capacity) can go down to 20 % of the rated capacity (corresponding to 80 % depth of discharge (DOD));
- periods with high solar irradiation, e.g. during hot and sunny days, which will bring the battery up to fully charged conditions, with the possibility that the battery could be overcharged.

4.3.5 Period of high state of charge

During hot and sunny periods for example, the battery will be operated at a high state of charge (SOC), typically between 80 % and 100 % of rated capacity.

A voltage regulator system normally limits the maximum battery voltage during the recharge period.

NOTE In a "self-regulated" PV system, the battery voltage is not limited by a charge controller but by the characteristics of the PV generator.

The system designer normally chooses the maximum battery voltage with regard to the conflicting requirements of "recover to a maximum state of charge (SOC)" as early as possible in the charging season but without substantially overcharging the battery.

The overcharge increases the gas production resulting in water consumption in vented cells. In valve-regulated lead-acid cells, the overcharge will cause a lesser increase of water consumption and gas emission but more heat generation.

Typically the maximum charge voltage is 2.4 V per cell for lead-acid batteries and 1.55 V per cell for nickel-cadmium batteries at the reference temperature specified by the manufacturer. Some regulators allow the battery voltage to exceed these values for a short period as an equalizing or boost charge. Charge voltage compensation shall be used according to the battery manufacturer instructions if the battery operating temperature deviates significantly from the reference temperature.

The expected life-time of a battery in a PV system even kept regularly at a high state of charge may be considerably less than the published life of the battery used under continuous float charge.

4.3.6 Period of sustained low state of charge

During periods of low solar irradiation, the energy produced by the photovoltaic array may not be sufficient to fully recharge the battery. The state of charge will then decrease and cycling will take place at a low state of charge. The low solar irradiation on the photovoltaic array may be a result of the geographical location combined with the winter periods, heavy clouds, rains or accumulation of dust on photovoltaic array.

4.3.7 Electrolyte stratification

Electrolyte stratification may occur in lead-acid batteries. In vented lead-acid batteries, electrolyte stratification can be avoided by electrolyte agitation or periodic overcharge whilst in service. In valve regulated lead-acid (VRLA) batteries, electrolyte stratification can be avoided by design or by operating them according to the manufacturer's instructions.

4.3.8 Storage

Manufacturers' recommendations for storage shall be observed. In the absence of such information, the storage period shall be estimated according to the climatic conditions as shown in Table 2 as below.

Table 2 — Limit values for storage conditions of batteries for photovoltaic applications

Battery type	Temperature range °C	Humidity %	Storage period for batteries	
			With electrolyte	Without electrolyte
Lead acid	-20 to +40	<90	Up to 6 months	1 – 2 years (dry charged)
Nickel-cadmium (Pocket plate type)	-20 to +50 (standard electrolyte)	<90	Up to 6 months	1 – 3 years (fully discharged, drained and sealed)
	-40 to +50 (high density electrolyte)			

With electrolyte, a lead-acid or nickel-cadmium battery shall be stored at full state of charge.

A loss of capacity may result from exposure of a battery to high temperature and humidity during storage.

NOTE The temperature of a battery stored in a container in direct sunlight, can rise to 60 °C or more in daytime. Choice of a shaded location or cooling should avoid this risk.

4.3.9 Operating temperature

The temperature range during operation experienced by the battery at the site is an important factor for the battery selection and the expected lifetime (see IEC 60721-1 for definitions of climatic conditions).

Manufacturers' recommendations for operating temperatures and humidity shall be observed. In the absence of such information, operating temperatures and humidity shall be those shown in Table 3.

Table 3 — Limit values for operating conditions of batteries for photovoltaic applications

Battery type	Temperature range °C	Humidity %
Lead-acid	-15 to +40	<90
Nickel-cadmium (standard electrolyte)	-20 to +45	<90
Nickel-cadmium (high density electrolyte)	-40 to +45	<90
NOTE 1 The manufacturer should be consulted for temperatures outside this range. Typically the life expectancy of batteries will decrease with increasing operating temperature.		
NOTE 2 Low temperature will reduce the discharge performance and the capacity of the batteries. For details, the manufacturer should be consulted.		

4.3.10 Charge control

Excessive overcharge does not increase the energy stored in the battery. Instead, overcharge affects the water consumption in vented batteries and consequently the service interval. In addition, valve-regulated lead-acid batteries may dry out resulting in a loss of capacity and / or overheating.

Overcharge can be controlled by use of proper charge controllers.

The parameters of the regulator shall take into account the effects of the PV generator design, the load, the temperature and the limiting values for the battery as recommended by the manufacturer.

Vented lead-acid or nickel-cadmium batteries including those with partial gas recombination shall have sufficient electrolyte to cover at least the period between planned service visits. Overcharge in valve-regulated lead-acid batteries shall be carefully controlled to reach optimum lifetime.

The water consumption is measured during the cycle test (see 8.4.5) and can be used together with the system's design information to estimate the service intervals.

4.3.11 Physical protection

Physical protection shall be provided against consequences of adverse site conditions, for example, against the effects of:

- uneven distribution and extremes of temperature;
- exposure to direct sun light (UV radiation);
- air-borne dust or sand;
- explosive atmospheres;
- flooding, water vapor condensation and water spray;
- earthquakes;
- shock and vibration (particularly during transportation).

5 General requirements

5.1 General

5.1.1 Construction

The lead acid battery shall consist of anode plates, cathode plates, separators, containers, etc and shall be capable of serving at ambient temperatures of -15 to +45 °C without abnormality. For sealed batteries with catalytic plug, however, the lower limit of ambient temperature shall be -5 °C in the monthly average.

The battery shall be equipped with anode terminal and cathode terminal, and in 6 V batteries the unit cells shall be connected with connecting links. The surface of the electrolyte shall be monitored by means of the liquid surface lines (the highest and the lowest) on the side of the container.

In the vented-type battery, the clearance between the cover and container shall be sealed with a sealing compound so that the gas generated in the battery does not come out from parts other than the vent hole. The sealed type battery shall be so constructed that the gas generated from the battery is returned to water by the catalytic plugs or the auxiliary electrodes and almost no gas comes outside in normal service conditions.

5.1.2 Plates

In lead acid batteries active materials of the positive and negative plates (lead-dioxide and sponge lead, respectively in a fully charged cell) shall supported on lead grid structures in all but the Planté type cells whose plates consists of scored pure lead sheets on which the active materials are produced during formation. In some cells, small amounts of antimony, along with traces of arsenic and other materials are often alloyed with the grid lead to strengthen the grids, facilitate grid casting and increase cell life. In applications where low self-discharge and/or low gassing rates are important lead-calcium alloys or pure lead grids are sometimes used.

The positive plates of a lead acid battery shall be not less than 2 mm thick.

Nickel-cadmium cells are presently manufactured in two basic types: sealed and vented. The "sealed" type cells also include a pressure relief vent, however, the vent assemblies associated with the two types are quite different from each other, as is the amount of electrolyte contained within the cell. To some extent, performance characteristics also differ between the sealed and vented designs. In addition, both sealed and vented cells are available with either sintered plate or pocket plate construction. Sintered plates are made by impregnating powdered active materials into sintered nickel support plates. With pocket designs the active materials are contained in perforated pockets formed into the support plates.

Sintered plate cells generally have lower internal resistance than equivalent pocket plate designs and are less affected by high rate or low temperature operation. However, pocket plate cells are more rugged and generally have longer lives.

5.1.3 Separator

An effective separator shall possess a number of mechanical properties; applicable considerations include permeability, porosity, pore size distribution, specific surface area, mechanical design and strength, electrical resistance, ionic conductivity, and chemical compatibility with the electrolyte. In service, the separator shall have good resistance to acid and oxidation. The area of the separator shall be a little larger than the area of the plates to prevent material shorting between the plates. The separators shall remain stable over the operating temperature range of the battery.

5.1.4 Container

Lead acid battery containers shall comply with the requirements of KS 1783.

5.1.5 Explosion-proof and spray preventive device

The device shall maintain the function stably and not allow the elution of any harmful impurity into the electrolyte under normal service condition.

5.1.6 Sealing construction

The sealing construction shall function stably for a long period and not allow the elution of any impurity deleterious to the performance of a battery into the electrolyte under normal service condition.

5.1.7 Terminals

The terminals shall be lug type or such that connection is made by means of bolts and nuts and not the tapered pillar type as normally used for starter batteries for vehicles and shall be corrosion resistant, and of such a design that cleaning at intervals is easily accomplished.

5.1.8 Electrolyte

The electrolyte for lead acid batteries shall be dilute sulphuric acid complying with KS 242 diluted with water conforming to EAS 121.

The density of the electrolyte in all fully charged vented batteries shall be in the range 1.26 kg/l to 1.30 kg/l at 25 °C unless otherwise specified by the manufacturer.

NOTE For valve-regulated batteries, the electrolyte is not accessible and, therefore, its density cannot be checked.

The electrolyte for nickel-cadmium batteries is a solution of potassium hydroxide in water with approximately 20 to 35 percent potassium hydroxide concentration.

The electrolyte in the nickel-cadmium system acts only as an ion transport medium and is essentially unchanged chemically during charge or discharge. The specific gravity of the electrolyte therefore remains relatively constant regardless of the state of charge of the cell.

Each cell or monobloc of a battery requiring addition of electrolyte (i.e. flooded cells) shall be provided with a means of indicating the highest and lowest permissible levels of electrolyte.

5.2 Mechanical endurance

Batteries for photovoltaic application shall be designed to withstand mechanical stresses during normal transportation and handling. Additional packing or protection shall be used for off-road conditions.

Particular care shall be taken while handling unpacked batteries. Manufacturer's instructions shall be observed.

In case of specific requirements regarding mechanical stresses, such as earthquakes, shock and vibration, these shall be individually specified or referred to the relevant standard.

5.3 Marking

Any marking required by this standard shall be durable and legible. In considering the durability of the marking, the effect of normal use shall be taken into account.

The durability of the marking shall be verified in accordance with 8.13.

6 Functional characteristics and specific requirements

6.1 Capacity

6.1.1 General

The main feature of a secondary cell or battery is its ability to store electrical energy. This storage capacity is expressed in ampere-hours (Ah) and varies with the conditions of use (electrolyte temperature, discharge current and final voltage).

To comply with this standard a battery shall be rated at the 20-hour rate of discharge (C_{20}) in accordance with 6.1.2. A battery may also be rated at the 10-hour rate of discharge (C_{10}) in accordance with 6.1.3.

Table 4 gives typical capacity ratings of batteries used in solar applications.

Table 4 — Typical capacity ratings of batteries in solar applications

Capacity Ah	Current A	Discharge period h	Final voltage	
			Lead-Acid	Nickel-Cadmium
			Volts per cell	Volts per cell
C_{240}	I_{240}	240	1.90	1.00
C_{120}	I_{120}	120	1.85	1.00
C_{20}	I_{20}	20	1.80	1.00
C_{10}	I_{10}	10	1.80	1.00
C_5	I_5	5	1.75	1.00

6.1.2 20-hour rate

The capacity of a battery at the 20-hour rate of discharge shall be determined in accordance with 8.1.

When tested in accordance with 8.1, the battery shall have a capacity of at least 90 % of the rated capacity on the first discharge and shall have a capacity equal to or greater than the rated capacity on or before the fifth discharge.

NOTE The user should specify the required capacity on delivery.

6.1.3 10-hour rate

If the battery is to be rated at the 10-hour rate, the capacity shall be determined in accordance with Annex A.

When tested in accordance with Annex A the battery shall have a capacity of at least:

- a) 85% of the rated capacity on the first discharge;
- b) 95% of the rated capacity within the first five cycles; and
- c) 100% of the rated capacity within the first 10 cycles.

NOTE The user should specify the required capacity on delivery.

6.2 Cycle life

The cycle endurance is the ability of a battery to withstand repeated charging and discharging. Normally the cycle endurance is given for cycles with a fixed depth of discharge and with the battery fully charged in each cycle. The batteries are normally characterized by the number of cycles that can be achieved before the capacity has declined to 80 % of rated capacity as per Table 5 below.

Table 5 — Cycle life and discharge characteristics of solar batteries

Type of battery	% depth of discharge	% self discharge per month	Number of cycles	Calendar years life
Lead acid				
Automotive	20	30	300 – 600	1 – 3
	80		20	
SLI modified (vented)	20	5 – 6	1000	1 – 3
Stationary — Vented	20	5 – 6	1000	
Stationary — Valve regulated	20	5 – 6	1200	
Valve regulated — AGM	20	2 – 3	6000	10
	80			
Valve regulated — Gel	20	2 – 3	6500	6 – 10
	80		2000	
Valve regulated — Tubular Gel	20	2	1200	20
	80		3500	
Traction (motive)	80	5 – 7	1500	4 – 6
	20	5 – 7	8000	
Tubular positive	50	1 – 3	3000	5 – 10
	20		5000	
Low antimony	80	3	1200	3
Sealed	20	2 – 6	400 – 1500	4 – 8
Planté	80	2	9000	25
Nickel Cadmium				
Pocket plates — Vented	20	2	9000	3 - 20
	80		1000	
Pocket plates — Valve regulated	20	3	10000	20
	80		3000	
Sintered plates — Vented	20	2	15000	8 – 20
	80	2	3000	
Fibre Nickel Cadmium (FNC)	80	2	3000	10

In photovoltaic applications the battery will be exposed to a large number of shallow cycles but at a varying state of charge. The cells or batteries shall therefore comply with the requirements of the test described in 8.2, which is a simulation of the PV system operation. The manufacturer shall specify the number of cycles the cells or batteries can achieve before the capacity has declined to 80 % of the rated capacity when tested in accordance with 8.2.

6.3 Charge-discharge efficiency

6.3.1 General

The efficiency requirement in 6.3.2 represents the absolute coulombic efficiency at a particular state of charge rather than an integrated average efficiency over a wide state of charge. This method of expressing efficiency is the most appropriate to the operating conditions of batteries used with photovoltaic power systems.

The efficiency of batteries vary according to their depth of discharge, being relatively low for batteries having a low depth of discharge.

6.3.2 Requirement

Where no data is available from the battery manufacturer, batteries shall have efficiencies stated in Table 6.

Table 6 — Battery Ah-efficiency at different states of charge at 20 °C and a cycle depth of less than 20 % of the rated capacity

State of charge (SOC)	Efficiency lead-acid cells	Efficiency nickel-cadmium cells
90 %	>85 %	>80 %
75 %	>90 %	>90 %
<50 %	>95 %	>95 %

6.4 Resistance to overcharge

Batteries used in photovoltaic power systems may be subject to periods of overcharge which may result in loss of battery capacity.

When tested in accordance with 8.12, the capacity loss shall not exceed 20 %.

6.5 Charge retention

The charge retention is the ability of a battery to retain capacity during periods of no charge, i.e. when not connected to a system, during transportation or storage. A battery for solar application shall show a high capability of charge retention. The charge retention shall be stated by the manufacturer but in no case shall the value be less than 82 %. The ability of a battery to retain charge shall be measured in accordance with 8.3.

NOTE Charge retention may affect the permitted storage and autonomy time.

6.6 Charge acceptance after deep discharge

6.6.1 General

Secondary batteries in photovoltaic systems may be left in various states of charge for extended periods especially during overcast and rainy seasons. A battery's ability to recover following a period in partial state of discharge is important in a photovoltaic power system.

6.6.2 Requirement

When tested in accordance with 8.5, a battery shall lose less than 25 % of its capacity.

6.7 Short-circuit current and internal resistance

This test is designed to yield values of the possible short circuit current (accuracy ± 10 %) capable to be delivered from the cell and monobloc battery when the external circuit has a negligible resistance

compared to that of the unit itself. The test also yields the values of the internal (d.c.) resistance of the cell or monobloc battery when this value is derived from the voltage vs. current relationship during a pulsed discharge of a defined magnitude. The values of short circuit current and internal resistance can be used for the sizing of safety devices such as fuses. It shall be noted that the short circuit current of a fully discharged unit is approximately 60 % of that of a fully charged unit.

The test shall be carried out in accordance with the provisions of 8.6.

6.8 Mechanical endurance

6.8.1 When tested in accordance with 8.7, 8.8, 8.9 and 8.10, a battery shall remain leak-tight and shall not exhibit a change in internal resistance of more than 25 % when tested in accordance with 8.6.

6.8.2 Vibration requirements

When subjected to either the sinusoidal or random vibration test the battery shall comply with the following.

- a) No battery cell or component shall show dimensional distortion beyond specified limits or cracking of cases or covers of either cells or batteries.
- b) There shall be no interruption of output and no irregular variation of voltage or current greater than 2 %.
- c) There shall be no mechanical failure of any part, electrolyte leakage or spillage of electrolyte at any time during the test or venting of gasses containing entrained electrolyte (except during charge of vented nickel-cadmium batteries).
- d) The minimum value of the insulation resistance shall be 0.25 MΩ, but after cleaning and drying the minimum value shall be 10 MΩ. There shall be no breakdown of insulation, stripping of metal plating from any component part, corrosion of metal parts, or loosening of protective coating from the battery container or cover or deterioration of battery identification markings.
- e) The battery shall comply with the rapid discharge capacity requirements.

6.9 Maximum permissible current

Batteries shall be suitable to maintain a current of $I_m = 40 \times I_{20}$ for 300 s and of $I_h = 200 \times I_{20}$ for 5 s, unless otherwise specified by the manufacturer, without distortion or other damage to the battery (see 8.11).

7 Test conditions

7.1 Sampling and preparation of batteries for testing

7.1.1 All tests shall be carried out on new, fully charged samples, except when the tests are used for re-determination of the actual capacity to assess degradation after long periods of service.

7.1.2 Samples shall be considered as new not later than six months after the date of manufacture.

7.1.3 Batteries shall be charged at an ambient temperature of $25\text{ °C} \pm 2\text{ K}$

- either for a period of 16 h,
- or until the current does not change by more than $0.1 \times I_{20}$ within two consecutive hours.

The charge will take place either:

- a) from constant voltage, advised by the manufacturer, or, if not available, from the values provided in Table 7.

Table 7 — Default charging parameters (constant voltage/PWM)

Cell Type	Voltage limit (V per cell) ^a	Voltage limit (V) ^a	Minimum duration of constant-voltage regulation at specific voltage limit (h)
Vented, lead-antimony	2.55	15.3	3
Vented, lead-calcium	2.66	16.0	3
VRLA, AGM (see manufacturer's specifications)	2.35	14.1	12
VRLA, gel (see manufacturer's specifications)	2.35 to 2.40	14.4	12
^a This value has to be within the system's operating voltage limits.			
NOTE Voltages specified for battery temperature at 25 °C + or - 3 °C.			
V per cell = volts per cell, AGM = Absorbed Glass Mat, Gel = gelled electrolyte.			

or

- b) from modified constant voltage (U_c as in a) with an initial charging current limitation of:

$$I_{\max} = 6 \times I_{20}.$$

The cells or batteries are considered as fully charged when either:

- during charging at constant current, the observed voltage and electrolyte density do not show any change beyond the tolerance of the measuring instruments, during a period of 2 h, taking into account changes in the temperature of the electrolyte, or
- during charging at constant voltage, the observed current and electrolyte density do not show any change beyond the tolerance of the measuring instruments, during a period of 2 h, taking into account changes in the temperature of the electrolyte unless other wise specified by the manufacturer.

7.1.4 Placement of batteries during testing

Throughout the duration of the tests, the battery shall be placed in a water bath at a temperature of 25 ± 2 °C except where the test is an accelerated simulation of a PV system. The terminal base of the battery shall be at least 15 mm but no more than 25 mm above the level of the water. If several batteries are in the same water bath, the distance between them shall be at least 25 mm.

7.1.5 Test samples shall be prepared in accordance with the following established procedures in the following standards:

- CD/04-2:2003 for modified lead acid batteries (vented types)
- IEC 60896-11 for stationary lead-acid batteries (vented types);
- IEC 60896-21 for stationary lead-acid batteries (valve-regulated types);
- IEC 61056-1 for portable lead-acid batteries (valve-regulated types);
- IEC 60622 for sealed nickel-cadmium batteries;
- IEC 60623 for vented nickel-cadmium batteries;
- IEC 62259 for nickel cadmium prismatic rechargeable single cells with partial gas recombination.

— IEC 60254-1 for traction lead acid batteries

7.2 Accuracy of measuring instruments

7.2.1 Voltage measurements

The instruments used shall be of an accuracy class 0.5 or better where required. The resistance of the voltmeters shall be at least 10 000 Ω/V (see IEC 60051 or IEC 60485).

7.2.2 Current measurements

The instruments used for current measurement shall be ammeters of an accuracy class equal to 0.5 or better. The entire assembly of ammeter, shunt and leads shall be of an accuracy class of 0.5 or better (see IEC 60051 or refer to IEC 60359).

7.2.3 Temperature measurement

For measuring temperature, thermometers shall be used having a suitable measuring range in which the value of each graduated division is not in excess of 1 °C. The absolute accuracy of the instruments shall be at least 1 °C.

NOTE As the electrolyte temperature cannot be measured directly in valve regulated cells and monobloc batteries, an alternative measuring point is chosen for giving a temperature reading as close as possible to that of the electrolyte. The preferred point of measurement is either the negative terminal or the cell wall in direct contact of the plates.

7.2.4 Electrolyte density measurement

For measuring electrolyte densities, hydrometers or other instruments shall be used with scales so graduated that the value of each division is not in excess of 0.005kg/l [5 kg/m³]. The absolute accuracy of the instruments shall be at least 0.005kg/l [5 kg/m³].

7.2.5 Time measurements

The time measurements shall have of an accuracy of ± 0.1 % or better where required.

7.2.6 Length and width measurements

The instruments used shall have an accuracy of ± 0.1 % or better where required.

7.2.7 Weight measurements

The instruments used shall have an accuracy of ± 1 % or better where required.

7.2.8 Gas volume measurements (valve regulated types)

The instruments used shall have an accuracy of ± 5 % or better where required.

7.2.9 Gas pressure measurements (valve regulated types)

The instruments used shall have an accuracy of ± 10 % or better where required.

7.3 Physical examination

Prior to the commencement of the electrical and environmental testing, each battery being tested shall be inspected to ensure that it complies with the requirements for PV applications as follows:

- a) mass and dimensions;
- b) minimum marking as detailed in Clause 10;
- c) correct warning labels;
- d) correct terminal connectors;

- e) damage to case, lid and terminal connectors;
- f) no signs of corrosion;
- g) no signs of electrolyte leakage;
- h) general standards of workmanship.

8 Test methods

8.1 Verification of rated capacity (20-hour discharge rate)

Test samples shall be set up in accordance with the applicable standards in 7.1.5. Tests to verify the rated capacity shall be performed using a current of I_{20} (A) for lead-acid batteries and $I_t/5$ (A) for nickel-cadmium batteries according to the relevant clauses in the standards listed in 7.1.5.

For the capacity test using a current of I_{120} (A) for lead-acid batteries or $I_t/120$ for nickel-cadmium batteries, the discharge shall be in accordance with parameters stated in Table 4 and the charging procedure shall be carried out according to the relevant clauses in the standards listed in 7.1.5

8.1.1 Apparatus

The apparatus listed in 7.2 is required.

8.1.2 Procedure

The procedure shall be as follows:

- a) Prepare the battery for test in accordance with 7.1.
- b) Monitor the temperature of one of the cells of each battery under test, or of each cell or monobloc if a single cell or monobloc is being tested. The cell chosen to monitor the temperature of the battery should not be a cell at either end of the battery.
- c) Discharge the battery at the C_{20} rate. The discharge shall commence between 1 h and 24 h after the battery has reached full charge, and shall be performed at a battery temperature of 25 ± 2 °C. The discharge current, I_{20} , shall be held within ± 2 % of the required rate.
- d) During the discharge, record the following at hourly intervals:
 - i) battery voltage;
 - ii) discharge current; and
 - iii) battery temperature.
- e) End the discharge when the battery reaches the final voltage specified by the manufacturer for photovoltaic applications or a voltage of:
 - i) 1.80 V for lead acid cells, or
 - ii) 1.00 V for nickel cadmium cells,
 if the manufacturer does not specify a final voltage.
- f) Determine the actual capacity from the following equation:

$$C_a = I_{20} \times t$$

where,

C_a = actual capacity, in ampere hours

I_{20} = discharge current, in amperes

t = discharge time in hours

g) Recharge the battery in accordance with 7.1.3

h) Perform steps (c) to (g) five times.

8.1.3 C_a shall be equal to, or higher than, C_{20} . If not, the procedure should be repeated. The rated value shall be reached at or before the fifth discharge.

8.1.4 Reporting the results

The following shall be reported:

- a) battery details
- b) the capacity of the battery at each of the five discharges
- c) reference to this test method

8.2 Cycle life

8.2.1 The test shall be carried out on at least three units (monoblocs or single cells). It shall have met the requirements of 8.1.3.

8.2.2 Throughout the whole test period the battery shall be kept at an ambient temperature of $25\text{ }^{\circ}\text{C} \pm 2\text{ K}$.

8.2.3 The battery shall be connected to a device where it undergoes a continuous series of cycles, each cycle comprising:

- a discharge for 3 h at a current $I = 3.4 \times I_{20}$, or a discharge for 2 h at a current $I = 5 \times I_{20}$ immediately followed by
- a recharge
 - for 9 h in case of discharge for 3 h at $I = 3.4 \times I_{20}$ or
 - for 6 h in case of discharge for 2 h at $I = 5 \times I_{20}$

at constant voltage U_c or with constant current I_c (see 7.1.3)

At the end of each 3 h or 2 h discharge period the on-load voltage U_f shall be recorded automatically or be otherwise measured by suitable means.

8.2.4 After a series of (50 ± 5) cycles the battery shall be recharged according to 7.1.3. Then the capacity shall be determined by discharging with $I = 3.4 \times I_{20}$ or $5 \times I_{20}$ until $U_f = n \times 1.65\text{ V}$. If the discharge time is greater than 3 h or 2 h respectively, then the battery shall undergo another series of (50 ± 5) cycles according to 8.2.3.

8.2.5 If in the course of this cycling the voltage U_f (see 8.2.3) falls below $n \times 1.65\text{ V}$, then cycling shall be interrupted and the battery shall be recharged according to 7.1.3. The capacity C_a shall then be determined according to 8.2.4. If the discharge time is less than 3 h or 2 h respectively, then the test shall be terminated.

8.2.6 The endurance is expressed as the total number of cycles according to 8.2.3 to which the battery can be submitted until the discharge time with $I = 3.4 \times I_{20}$ is less than 3 h or discharge time with $I = 5 \times I_{20}$ is less than 2 h. This translates to the termination of the endurance test when the capacity falls below 80 % of that determined in 8.1.3.

8.3 Charge retention test

A battery which has met the requirements of 8.1.3 shall be charged according to 7.1.3. The surface shall be cleaned and dried. It shall then be stored on an open circuit for 92 days (for vented lead acid types) or 120 days (for valve regulated lead acid types) at an ambient temperature of $20\text{ °C} \pm 2\text{ K}$, or $25\text{ °C} \pm 2\text{ K}$.

The battery shall then be discharged according to 8.1.2 with the discharge current I_{20} .

The duration t of the discharge to $U_f = n \times 1.75\text{ V}$ shall be equal to, or higher than, 15 h. The measured capacity shall be not less than 82 % of the actual capacity.

8.4 Cycle endurance test in photovoltaic application (extreme conditions)

In photovoltaic applications the battery will be exposed to a large number of shallow cycles but at different states of charge. The cells or batteries shall therefore comply with the requirements of the test below, which is a simulation of the photovoltaic energy system operation.

The cycle endurance test is an accelerated simulation in extreme conditions of the battery operation in a photovoltaic energy system and shall be conducted by submitting the cells or monobloc batteries to a period of 150 cycles (50 cycles with the phase A and 100 cycles with the phase B).

Test samples shall be set up in accordance with the applicable standards listed in 7.1.5 after control of the capacity test in 8.1.

Start the test with the battery fully charged. Bring the battery to a temperature of $40\text{ °C} \pm 3\text{ °C}$ and stabilize for 16 h. Maintain the battery at $40\text{ °C} \pm 3\text{ °C}$ throughout the test.

8.4.1 Phase A: shallow cycling at low state of charge

▪ Lead-acid batteries

- a) Discharge the battery with a current I_{10} (A) during 9 h or until 1.75 V/cell is reached.
- b) Recharge 3 h with a current $1.03 \times I_{10}$ (A)
- c) Discharge 3 h with a current I_{10} (A).

▪ Nickel-cadmium batteries

- a) Discharge the battery with a current $I_t/10$ (A) during 9 h or until 1.00 V/cell is reached.
- b) Recharge 3 h with a current $1.03 \times I_t/10$ (A)
- c) Discharge 3 h with a current $I_t/10$ (A)

For both battery types, repeat b) and c) 49 times. Recharge the battery to the fully charged condition according to the manufacturer recommendations and continue the phase B. Phase A is summed up in Table 8.

Table 8 — Phase A: Shallow cycling at low state of charge

	Discharging time h	Charging time h	Lead-acid current A	Nickel-cadmium current A
a)	9		I_{10} (A) (or stopping at 1.75 V/cell)	$I_t / 10$ (A) (or stopping at 1.00 V/cell)
b)		3	$1.03 I_{10}$ (A)	$1.03 I_t / 10$ (A)
c)	3		I_{10} (A)	$I_t / 10$ (A)
Repeat b) to c) 49 times and continue to phase B				

8.4.2 Phase B: shallow cycling at high state of charge

▪ Lead-acid batteries

- a) Discharge the battery for 2 h with a current $1.25 I_{10}$ (A)
- b) Recharge 6 h with a current I_{10} (A). The charge voltage shall be limited to 2.40 V/cell, unless otherwise specified by the manufacturer.

▪ Nickel-cadmium batteries

- a) Discharge the battery for 2 h with a current $1.25 I_t / 10$ (A)
- b) Recharge for 6 h with a current $I_t / 10$ (A). The charge voltage shall be limited to 1.55 V/cell unless otherwise specified by the manufacturer.

For both batteries, repeat a) and b) 99 times and then perform a capacity determination according to 8.4.3. Phase B is summed up in Table 9.

Table 9 — Phase B: Shallow cycling at high state of charge

	Discharging time h	Charging time h	Lead-acid current A	Nickel-cadmium current A
a)	2		$1.25 I_{10}$ (A)	$1.25 I_t / 10$ (A)
b)		6	I_{10} (A) (charge voltage limited to 2.40 V/cell unless otherwise specified by the manufacturer)	$I_t / 10$ (A) (charge voltage limited to 1.55 V/cell unless otherwise specified by the manufacturer)
Repeat a) to b) 99 times				

8.4.3 Capacity check

After the phase B, the battery is cooled down to the temperature defined in the relevant standard as described in 7.1.5 and stabilized at this value for 16 h. The capacity test (C_{20} for lead-acid batteries and C_5 for nickel-cadmium batteries) is carried out according to the relevant standard as described in 7.1.5.

8.4.4 End of test condition

- Capacity is checked after each period of 150 cycles (phases A + B).
- The value of actual capacity determined in 8.4.3 shall be recorded.
- The cycle life shall be expressed in number of 150 cycle (A+B) sequences completed.
- The test is finished:

- During the phase A: when the cell voltage measured in discharge is lower than 1.5 V/cell for lead acid batteries and 0.8 V/cell for nickel-cadmium batteries.
- After the phase B: when the checked capacity measured in 8.4.3 is lower than 80 % of the rated capacity.

8.4.5 Water consumption of flooded battery types and cells with partial gas recombination

During the cycle endurance test, vented type cells or monoblocs may be topped up with water. The amount of water added shall be measured and reported.

8.4.6 Requirements

The number of complete cycle sequences (150 cycles) achieved at the end of the test shall be not less than the value stated by the manufacturer.

8.5 Charge acceptance after deep discharge

8.5.1 The test shall be carried out on at least three units (monoblocs or single cells). The battery shall have met the requirements of 8.1.3.

8.5.2 A load resistor is selected so that, from a voltage of $n \times 2$ V, a current of $I = 40 \times I_{20} \pm 10$ % results. The resistor shall be connected to the terminals of the battery, which shall then be stored for 360 h at an ambient temperature of $20^\circ\text{C} \pm 2$ K or $25^\circ\text{C} \pm 2$ K.

8.5.3 The load resistor shall then be disconnected from the terminals and the battery shall be recharged at a constant voltage U_c (see 7.1.3) for a period of 48 h with an available current between $6 \times I_{20}$ and $10 \times I_{20}$.

8.5.4 At the end of the charging period, the battery shall remain on open circuit at $25^\circ\text{C} \pm 5$ K for 16 h to 24 h. It shall then be discharged according to 8.1.2.

8.5.5 The resulting capacity in ampere-hours shall be $\geq 0.75 \times C_{20}$ (Ah).

8.6 Short-circuit current and internal resistance determination

8.6.1 The test shall be carried out on a minimum of three cells which, after submission to the capacity test in accordance with 8.1, have been found to have a capacity C_a .

8.6.2 After preparation in accordance with 7.2, the cells or batteries shall be placed in a chamber at the appropriate ambient temperature until the temperature of the electrolyte reaches $(20 \pm 2)^\circ\text{C}$.

8.6.3 The discharge characteristic $U = f(I)$ shall then be established by determining two of its points in the following way.

8.6.3.1 First point (U_1, I_1)

After 20 s discharge at a current $I_1 = 4 I_{10} \dots 6 I_{10}$ (A) the voltage and current are read and give the first point. The discharge shall be interrupted after 25 s maximum; without recharging and, after an open-circuit stand of 2 min to 5 min, the second point is determined.

8.6.3.2 Second point (U_2, I_2)

After 5 s discharge at a current $I_2 = 20 I_{10} \dots 40 I_{10}$ (A) the voltage and current are read and give the second point.

8.6.4 The characteristic $U = f(I)$ is linearly extrapolated to $U = 0$ (V). The intercept indicates the short-circuit current I_{sc} . The internal resistance (R_i) may also be determined.

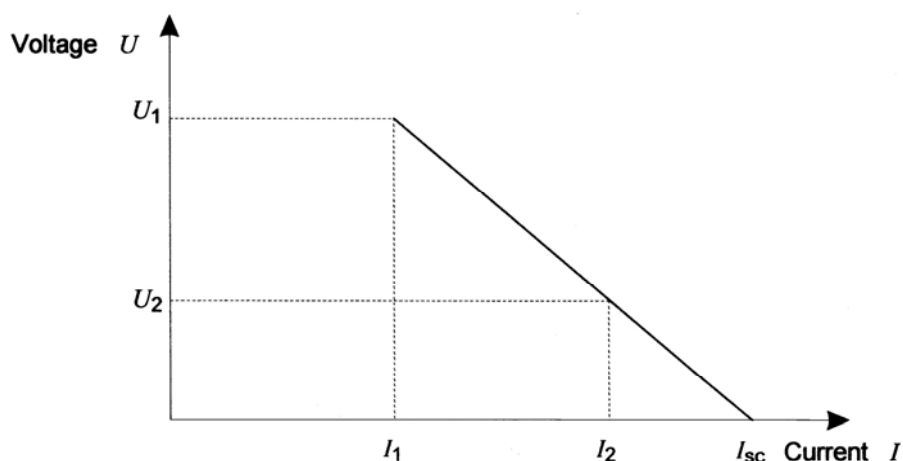


Figure 1 — Discharge characteristic $U = f(I)$

From Figure 1, it follows that

$$I_{sc} = \frac{U_1 I_2 - U_2 I_1}{U_1 - U_2} \quad \text{A}$$

$$R_i = \frac{U_1 - U_2}{I_2 - I_1} \quad \Omega$$

NOTE 1 The voltage is measured at the terminals at the outlet of each cell or monobloc in order to ensure that no external voltage drop interferes with the test. A typical test circuit is shown in Figure 2. The values of short-circuit current and internal resistance obtained in this test refer to a single cell or monobloc. However, the resistance of intercell connections has to be taken into account when calculating the short-circuit current and internal resistance for a complete battery.

NOTE 2 This test method provides information in stabilized test conditions and does not indicate dynamic reactions occurring, for example, during the first few milliseconds of a short circuit. The results of this test have an accuracy which is of the order of 10 %.

NOTE 3 In the case of very large cells the I_r and S_{cc} value can be derived from smaller cells having the same plate size and type

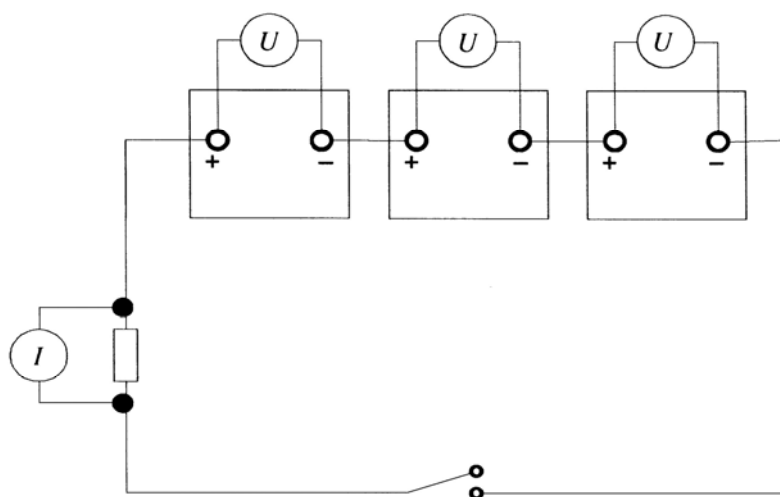


Figure 2 — Typical test circuit

8.7 Mechanical endurance tests — Thermal cycling

8.7.1 Procedure

The procedure shall be as follows:

- a) Select a battery that has satisfied the capacity requirement of 8.1 and the charge retention requirement of 8.3.
- b) Prepare the battery for test in accordance with 7.2.
- c) Determine the internal resistance of the battery in accordance with 8.6.
- d) Maintain the battery at an ambient temperature of 0 ± 2 °C for 12 h and then at an ambient temperature of 50 ± 2 °C for 12 h
- e) Perform Step (d) six times.
- f) Maintain the battery at an ambient temperature of 10 ± 2 °C for 12 h and then at an ambient temperature of 40 ± 2 °C for 12h.
- g) Perform step f) 28 times.
- h) Repeat steps b) and c).

8.8 Mechanical endurance tests — Bump test

8.8.1 Procedure

The procedure shall be as follows:

- a) Select a battery that has satisfied the capacity requirement of 8.1 and the charge retention requirements of 8.3.
- b) Prepare the battery for test in accordance with 7.1.
- c) Determine the internal resistance of the battery in accordance with 8.6.
- d) In accordance with IEC 60068-2-29, subject the battery to a series of 1000 bumps of 6 ms duration at 245 m/s^2 .
- e) Repeat steps b) and c)

8.8.2 Any leakage of electrolyte or any change in internal resistance of greater than 25 %.

8.9 Mechanical endurance tests — Drop test

8.9.1 Procedure

The procedure shall be as follows:

- a) Select a cell or monobloc that has satisfied the requirements of 8.1.3 and the charge retention requirement of 8.3.
- b) Prepare the battery for test in accordance with 7.1.
- (c) Determine the internal resistance of the battery in accordance with 8.6.

- d) In accordance with IEC 60068-2-31, drop the cell or monobloc twice on its base on a solid floor from a height of 100 mm.
- e) Repeat steps b) and c).

8.9.2 Any leakage of electrolyte or any change in internal resistance of greater than 25 %.

8.10 Mechanical endurance tests — Vibration test

8.10 Procedure

The procedure shall be as follows:

- a) Select a cell or monobloc that has satisfied the requirements of 8.1.3 and the charge retention requirement of 8.3.
- b) Prepare the battery for test in accordance with 7.1.
- c) Determine the internal resistance of the battery in accordance with 8.6.
- d) In accordance with IEC 60068-2-6, mount the cell or monobloc in an upright position and vibrate it:
 - i) at 6 mm constant displacement from 5 Hz to 13 Hz; and
 - ii) at 19.6 m/s from 13 Hz to 150 Hz.

This step shall be performed in three mutually perpendicular planes in turn.

- e) Repeat steps b) and c)

8.10.2 Any leakage of electrolyte or any change in internal resistance of greater than 25 %.

8.11 High rate discharge capability

8.11.1 A fully charged battery (7.1.3) shall be kept on open circuit for 16 h to 24 h.

8.11.2 It shall then be discharged with the current $I_m = 40 \times I_{20}$ for 300 s.

8.11.3 The battery shall be recharged according to 7.1.3 and shall be left on open circuit at $25^\circ\text{C} \pm 2\text{ K}$ for 16 h to 24 h.

8.11.4 It shall then be discharged with the current $I_h = 200 \times I_{20}$ for 5 s.

8.11.5 Upon inspection, no apparent physical damage from these discharges shall be observable.

8.11.6 The battery shall be recharged according to 7.1.3 and shall then be discharged with the current I_m . The duration t of the discharge to $U_f = n \times 1.34\text{ V}$ shall be equal to, or higher than, 150 s.

8.11.7 If the manufacturer has declared values of I_m and I_h other than those in 6.9, the test currents of 8.11.2 and 8.11.4 shall be amended accordingly.

8.12 Overcharge resistance test method

8.12.1 Apparatus

The apparatus listed in 7.2 are required.

8.12.2 Procedure

The procedure shall be as follows:

- a) Select a battery that has satisfied the capacity requirement of 8.1.3 and record the available capacity of the battery.

- b) Prepare the battery for test in accordance with 7.1.
- c) Maintain a battery temperature of 40 ± 2 °C.
- d) Charge the battery for 250 hours at the $0.3C_{20}$ rate.
- e) Allow the battery to cool to a temperature of 25 ± 2 °C.
- f) Recharge the battery in accordance with 7.1.3.
- g) Determine the actual capacity of the battery in accordance with 8.1.3.

8.12.3 Calculation

The loss of capacity, expressed as a percentage, shall be determined from the following equation:

$$C_{L,40} = \frac{(C_{as} - C_{ae}) \times 100}{C_{as}}$$

where,

$C_{L,40}$ = loss of capacity, at 40 °C, per 250 h, expressed as a percentage

C_{as} = actual capacity at the start of the test, in ampere hours

C_{ae} = actual capacity of the battery at the end of the test, in ampere-hours.

NOTE The percentage loss of capacity per month at 25 °C is half that at 35 °C.

8.12.4 Reporting the results

The following shall be reported:

- a) Battery details.
- b) The percentage loss of capacity determined in 8.12.3.
- c) Reference to this test method.

8.13 Content and durability of required markings

8.13.1 The test shall be carried out on three of the required markings in their definitive size, form, material and execution. Required markings may be printed, painted or moulded on the case or cover or included in a label affixed to the case or cover.

8.13.2 The test shall consist of visual verification of a) the presence and b) the legibility of all the required markings before and after exposure to selected chemicals.

8.13.3 The durability of the marking shall be tested as follows:

8.13.3.1 Test with water and aliphatic solvent

The procedure is as follows:

- a) A label or marking shall be rubbed for 15 s with a piece of cloth soaked with water and again for 15 s with a piece of cloth soaked with petroleum spirit, dried in air and then inspected visually.
- b) The petroleum spirit used for this test shall be n-hexane (C_6H_{14} – alkane C_6) with an initial boiling point of 65 °C, a dry point of approximately 69 °C, a density of 0.7 kg/l and a maximum aromatic hydrocarbon content of 0.1 % per volume.

8.13.3.2 Test with neutralizing solutions

The procedure is as follows:

A new label or marking shall be rubbed for 15 s with a piece of cloth soaked with a saturated solution of sodium carbonate (Na_2CO_3) or bicarbonate (NaHCO_3) in water, dried in air and then inspected visually.

8.13.3.3 Test with electrolyte

The procedure is as follows:

A new label or marking shall be rubbed for 15 s with a piece of cloth soaked with a solution of 40 % in weight of H_2SO_4 in water, washed with water, dried in air and then inspected visually.

8.13.4 Each required label or marking shall be visually inspected, fully described and depicted photographically before and after the application of the test chemical.

IMPORTANT: Solvents shall not be used to clean cells and monobloc batteries as otherwise damage to the plastic components may result. Approved cleaning fluids are only those expressly specified by the manufacturer.

NOTE The content of the required markings is specified in 5.3.

9 Guarantee

Guarantees against faulty workmanship and material for a period specified by the manufacturer but of at least one year shall be given.

10 Marking

10.1 Marking on battery

The following information shall be permanently marked on the cell or battery:

- a) The name of the manufacturer or supplier or his/her trademark and type reference number;
- b) Country of origin;
- c) Type of battery;
- d) Date of manufacture (month and year);
- e) Rated capacity at C_{20} discharge rate at 25 °C;
- f) Nominal voltage; and
- g) Clearly marked and sized terminal polarity signs.
- h) Electrolyte density (fully charged at 25 °C);

10.2 Information to be supplied on the package

Information relevant to safety recommendations as required by local, national or international regulations shall be marked on the cell or monobloc package.

The manufacturer or supplier shall supply the following information:

- a) recommended depth of discharge;
- b) cycle life;
- c) maximum charge voltage, float voltage and load disconnect voltage;
- d) temperature compensation curves;
- e) type of battery cell and


- f) voltage (battery);
- g) manufacturer's or supplier's type reference;
- h) ampere-hour capacity with rate of discharge and end voltage at the chosen reference temperature;
- i) electrolyte density (fully charged at the chosen reference temperature);
- j) statements on safety recommendations, operation and maintenance.


10.3 Marking of polarity

10.3.1 General provision for marking of cell polarity

To comply with this standard, stationary battery cells and monoblocs shall carry the polarity marking, at least of the positive terminal.

10.3.2 Form of marking

The marking shall take the form of the symbol , indented or in relief, on the lid adjacent to the positive terminal.

The marking of the negative terminal shall take the form of the symbol , indented or in relief, on the lid adjacent to the negative terminal.

10.3.3 Symbols used for marking and their dimensions

Symbols used for marking of the polarity shall be in accordance with IEC 60417.

The marking of the positive terminal shall be in accordance with the symbol 60417-IEC-5005, Positive polarity.

The marking of the negative terminal shall be in accordance with the symbol 60417-IEC-5006, Negative polarity.

The actual value of the dimension "a" of these symbols shall be greater than, or equal to, 5 mm.

NOTE A dimension "a" of 5 mm corresponds to a total length of each arm of the symbol equal to 6 mm.

11 Recommended use of tests

11.1 Type test

Type tests are:

- the rated capacity test and the charge retention test;
- the endurance test in cycling;
- the cycling endurance test in photovoltaic application (extreme conditions).

The minimum number of cells or monobloc batteries shall be as specified in the relevant standards listed in 7.1.5.

The cycling endurance test in photovoltaic application shall be performed with a minimum of six cells or 2 monobloc batteries.

11.2 Acceptance test

11.2.1 Factory test

The acceptance test shall be agreed between the customer and the supplier. Compliance to marking, labelling or to the rated capacity may be verified.

11.2.2 Commissioning test

A commissioning test is recommended to prove the integrity of the installed battery system by means of a capacity test.

12 Safety

Refer to the manufacturer's instructions for procedures to be observed during installation, commissioning, operation, taking out of service, and disposal.

13 Documentation

Refer to the manufacturer's documentation for transport and storage, commissioning, putting into service, operation and maintenance.

The manufacturer shall advise if there are special considerations for the initial charging of batteries with only the solar array available as the power source.

Annex A (informative)

Ten-hour rate capacity (10 hour discharge rate)

A.1 Apparatus

The apparatus listed in 7.2 is required.

A.2 Procedure

The procedure shall be as follows:

- a) Prepare the battery for test in accordance with 7.1.
- b) Monitor the temperature of one of the cells of each battery under test, or of each cell or monobloc if a single cell or monobloc is being tested. The cell chosen to monitor the temperature of the battery should not be a cell at either end of the battery.
- c) Discharge the battery at the $0.1C_{10}$ rate. The discharge shall commence between 1 h and 24 h after the battery has reached full charge, and shall be performed at a battery temperature of 25 ± 2 °C. The discharge current shall be held within ± 1 % of the required rate.
- d) During the discharge, record the following at hourly intervals:
 - i) battery voltage;
 - ii) discharge current; and
 - iii) battery temperature.
- e) End the discharge when the battery reaches the final voltage specified by the manufacturer for stand-alone applications or a voltage of:
 - i) 1.85 V for lead acid cells, or
 - ii) 1.00 V for nickel cadmium cells,
 if the manufacturer does not specify a final voltage.
- f) Determine the actual capacity from the following equation:

$$C_a = I \times t$$

where,

C_a = actual capacity, in ampere hours

I = discharge current, in amperes

t = discharge time in hours

- g) Recharge the battery in accordance with 7.1.3
- h) Perform steps b) to g) ten times.

A.3 Reporting the results

The following shall be reported:

- a) battery details
- b) the capacity of the battery at each of the ten discharges
- c) Reference to this test method

Annex B (informative)

Lead acid battery technologies

B.1 Battery applications

Lead acid batteries are almost universally used in PV systems because of their low cost and availability. A few special application PV systems use nickel-cadmium batteries or advanced technologies to improve reliability and/or to reduce maintenance. This is a very small percentage of the applications, and as a result, this document will only address the lead-acid battery technology. At present, the dominant lead-acid battery technologies used in PV systems are divided into two major groups, vented (flooded) lead-acid batteries and valve-regulated lead-acid batteries that have their electrolyte contained in a medium of either glass fibres or gel. Batteries from both subgroups are designed for starting, lighting, and ignition (SLI), deep-cycle marine/recreational vehicle (RV), deep-cycle golf cart, deep-cycle industrial motive power, small float service stationary uninterruptible power supply (UPS), and large stationary float service applications. Each of the above battery applications will also have a number of options available for the six major battery markets indicated above. Generally standalone PV systems use batteries designed for the SLI automotive, deep-cycle marine/RV, or deep-cycle motive power golf cart markets. The most relevant to PV systems are the vented and VRLA deep-cycle batteries. Even though automotive SLI batteries are not designed for deep cycling and have a significantly shorter cycle-life, they are universally available and are the lowest initial cost short-term option. The common deep-cycle marine/RV batteries are designed to be more tolerant to deep cycling. Motive power golf cart batteries are designed for deep cycle service with cycle-life ratings significantly greater than the deep-cycle marine/RV batteries. Motive power and/or golf cart batteries are not readily available in auto parts stores.

B.2 Vented lead acid batteries

When used and maintained properly, the vented lead acid battery has a long and successful track record for providing power in SLI, deep-cycle motive power, and standby stationary float service applications. Each of these major categories uses batteries specifically designed for that application. The key for successful battery operation is to use the appropriate battery for the application, provide the required maintenance, and provide a cycle profile consistent with the battery design.

If SLI batteries are used in PV systems, it is important to understand their use, design, and limitations. Most vented SLI batteries now used in developed countries are of the lead-calcium open vent design. SLI batteries are designed to be used for short high-rate discharges in engine starting and to provide brief lighting loads. The battery grids are specially designed for this application by making them thin for more surface area and alloying them with lead-calcium to reduce water consumption and maintenance. The thin grids are susceptible to cracking and grid corrosion from the mechanical stresses of cycling and the normal electrochemical wear out processes.

Another group of SLI batteries used in PV systems in developing countries have a similar design to the above SLI batteries except that they use a low percentage of antimony (~2% to 3%) in the lead grids and they have slightly thicker grids. These batteries are similar to SLI batteries used in developed countries up until the 1960s, but they are still common in developing countries and are similar to deep-cycle marine/RV batteries presently in use in developed countries. In these batteries, the grids are slightly thicker and the

Antimony grid alloy is more resistant to cracking, stratification, and premature capacity loss. Cycle-life is greater than the lead-calcium batteries but is much less than the motive power and golf cart batteries. In many countries, this may be the only battery available, and with proper care, they can have an average life of 1.5 years.

The marine/RV batteries are a deep-cycling battery that is very popular with the PV industry. The construction is similar to the lead-antimony SLI batteries except that the grids are thicker, more antimony is used as an alloying element in the grids, the positive paste active material is formulated

for cycling applications, and more space is provided for plate sediment. The combination of these design improvements results in a significant improvement in cycling ability without a significant increase in cost.

The deep-cycle golf cart batteries are medium-duty cycling batteries that are also very popular with the PV industry. The construction of these batteries includes grids with a medium thickness of 3 to 4 mm, a grid alloy with a relatively high antimony content in the 4 % to 6 % range, a positive plate active material designed for deep-cycling, and more space for plate sediment. The grid thickness provides extra strength and excess metal to delay the normal wear out mechanisms of grid corrosion and active material shedding. The additional antimony provides more resistance to grid corrosion and minimizes capacity loss over the life of the battery. A more robust positive active material is more tolerant to cycling stresses and maintains capacity over the life of the battery. Typically, the deep-cycle battery designs require more watering and maintenance. The cost of deep-cycle golf cart batteries is somewhat more than marine/RV batteries, but the cycle-life can be much greater. Due to volume production, the deep-cycle golf cart batteries may provide the lowest life cycle cost option in properly designed small stand-alone PV systems.

Industrial motive power forklift batteries represent the most robust battery designs for deep-cycle battery applications. The major differences between golf cart batteries and motive power forklift batteries are the plate thickness and the rating process. Industrial motive power truck battery plate thickness is usually in the 5 to 6 mm range, and the capacity rating is usually at the 6 h rate. Golf cart batteries, on the other hand, are rated in minutes at a 75 ampere discharge rate or at the 20 h rate. This rating difference results in industrial motive power forklift batteries that are more conservatively sized. The cycle-life of these batteries is generally more than twice that of golf cart batteries, but their cost is also higher.

Industrial stationary batteries are also available for PV systems. These batteries can be used in deep-cycling and shallow-cycling applications with good results, but they can be more costly than motive power batteries. Some cycling stationary batteries are designed to have a much lower water consumption rate compared with deep-cycle motive power batteries. This can be an important consideration in PV system design.

B.3 VRLA batteries

VRLA batteries first became available in the early 1980s and have enjoyed a steady growth in production since then. VRLA batteries now represent a significant portion of the PV battery market. The VRLA technology is one of the most important lead-acid battery developments in the twentieth century. The early marketing strategies promoted this battery as a "sealed" or "maintenance free" battery, which it is not. The VRLA battery uses the oxygen recombination cycle to return most of the gas produced from electrolysis back into water. Small quantities of water may be lost from venting of excess gas and from internal grid corrosion. VRLA batteries cost more, degrade faster at high temperatures, require more stringent charge control, and may have a lower cycle-life than the vented alternative. The impetus for using VRLA batteries is due primarily to the fact that no watering is required, minimal electrolyte residue is left on the battery terminals, no special provisions for venting hydrogen gas other than room ventilation is usually required, installation requires less floor space, and the electrolyte is held immobilized in a glass mat or gel, which makes transportation safer and easier.

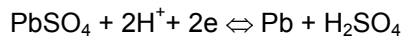
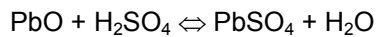
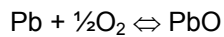
VRLA batteries have three design features that are unique with respect to their vented counterparts. These unique features are the captive electrolyte, a cell pressure valve, and the oxygen recombination cycle. The Captive electrolyte is suspended in either glass fibres called the absorbed glass mat (AGM) or in the silica gel. In AGM and gel batteries, the hydrogen ions produced at the negative plate and oxygen gas produced at the positive plate recombine electrochemically at the negative plates to conserve water. The VRLA battery technology does occasionally vent a very small amount of hydrogen and oxygen gas when it is under charge; consequently, the VRLA battery should be installed in a ventilated enclosure. The venting occurs when a low-pressure gas relief valve allows excess gas to vent when the battery reaches its maximum internal pressure. The valve also prevents air from entering back into the battery and causing negative plate discharge from atmospheric oxygen. The valve is a critical part of the oxygen recombination cycle because it prevents

atmospheric oxygen from entering the battery. The oxygen recombination cycle in Equation (B.1) includes the following chemical reactions:

Positive plate releases O₂ on charge



O₂ passes through AGM or gel to the negative plate



The required maintenance on VRLA batteries in stand-alone PV systems as compared with stationary float service applications is less than on deep-cycle vented lead-acid batteries. VRLA stand-alone PV system maintenance usually involves retorquing electrical interconnections, removing corrosion, measuring cell or monoblock voltages, and ensuring that the battery charger is working properly and meeting manufacturer's charge requirements.

B.4 Battery selection

Battery selection is dependent on battery availability, application, performance, cost, and system size. Because lead-acid batteries are heavy and contain sulfuric acid, shipping them can be difficult and result in damaged batteries. In many remote or developing country locations, it may be more practical to use local batteries, because replacement batteries may be needed in the future. When vented deep-cycle lead antimony batteries are available, they may be the lowest life cycle cost option. In applications where battery watering is not possible, or very expensive, or where shipping of liquid electrolyte is difficult, the VRLA battery can be a cost-effective option. With larger PV systems, the batteries will also need to be larger. Generally, the maximum number of parallel strings is four. Above this size, larger batteries should be used. The larger batteries are typically the deep cycle industrial forklift batteries or large stationary batteries. These batteries can be used in battery banks with capacities well over 10 000 Ah.

Annex C (informative)

Lead-acid battery characteristics

C.1 Self-discharge

All lead-acid batteries are subject to self-discharge or "local action" at all times. The effect of self-discharge only becomes a problem when batteries are left in storage without freshening charges. The self-discharge rate is a function of temperature, grid alloy, battery age, acid-specific gravity, and battery design. Self-discharge is a result of ongoing internal electrochemical reactions that essentially act as a continuous battery load. The most effective method to minimize self-discharge is to lower battery temperature. Lead-calcium grid alloys also greatly reduce self-discharge. Damage to batteries in storage due to self-discharge is only prevented by providing freshening charges on a regular basis.

The self-discharge rate for new-vented deep-cycle high-antimony batteries is about 2.5 % per week at 25 °C. The self discharge rate increases dramatically at 40 °C to over 5 % per week and decreases to less than 1 % per week at 0 °C. The self-discharge rate also increases significantly as the battery ages. Generally battery manufacturers will recommend a freshening charge every month or two for most vented deep-cycle batteries.

The self-discharge rate for a deep-cycle vented low-antimony grid alloy battery is about 1 % per week, whereas the lead-calcium alloys grids and VRLA batteries are typically less than 1 % per week at 25 °C. For VRLA batteries at 40 °C, the self-discharge rate is about 2.5 % per week, and at 0 °C, the self-discharge is near zero. The vented lead-calcium battery usually has only a slightly higher self-discharge rate compared with the VRLA battery. Battery manufacturers recommend a freshening charge about every six to seven months for vented lead-calcium and VRLA batteries.

C.2 Temperature effects

Battery temperature has a significant impact on cycle-life, capacity, charge voltage, electrolyte-specific gravity, and water consumption. Most lead-acid batteries are rated for operation at 25 °C; therefore, most battery specifications will be for operation at 25 °C. If the battery is used at other temperatures, then the specifications for cycle-life, capacity, charge voltage, electrolyte specific gravity, and water consumption will need to be adjusted accordingly.

The useful life of vented stationary float-service batteries will decrease by about 50% if the battery temperature increases 10 °C (35 °C battery temperature). If the battery operating temperature drops 10 °C to 15 °C, then the life will increase by about 10%. Although the exact temperature/life relationship for deep cycle batteries is not known, a similar relationship should hold because the degradation mechanism is the same as for float-service batteries.

Cycle-life of VRLA batteries is much more dependent on temperature, but the exact value of reduction in cycle-life is not known. However, it is known that the VRLA cycle-life reduction is greater than that of deep-cycle batteries for every 10 °C increase in battery temperature over 25 °C.

The capacity of all lead-acid batteries is affected by temperature. The capacity temperature relationship is not linear, but for most operating temperatures, a 1 %/°C temperature/capacity relationship is acceptable. As the rated capacity is at 25 °C, the capacity increases above 25 °C and decreases below 25 °C by the specified Amount.

Battery charge or regulation voltage needs to be adjusted by about -0.005 V/°C/cell as the battery temperature changes. The battery temperature compensation value for a specific battery is normally provided by the battery manufacturer. Above 25 °C, the regulation voltage needs to be reduced, and below 25 °C, the regulation voltage needs to be increased. Equation (C.1) is the formula for cell temperature compensated regulation voltage:

$$V_r/\text{cell (Temp Comp)} = ((\text{Bat Temp} - 25\text{ °C}) \times -0.005) + V_r/\text{cell @ } 25\text{ °C} \quad (\text{C.1})$$

The need for temperature-compensated regulation voltage in PV systems occurs when battery temperatures deviate from 25 °C. Without temperature compensation, the lead-acid battery will not be fully charged at low temperatures and will be excessively charged at high temperatures.

C.3 Electrolyte management

Vented deep-cycle lead-acid batteries require addition of pure water to the electrolyte. Usually, water additions are required every one to six months depending on battery design and how old the battery is. Older batteries require more water. Only very rarely will vented batteries require more electrolytes. Electrolyte additions would only be needed if a cell leaks electrolyte. VRLA batteries generally cannot be watered and thus do not require any water additions.

Water consumption increases at higher battery temperatures and decreases at lower temperatures, and thus, maintenance should be increased or decreased accordingly. Most of the increased water loss is due to the lower electrolysis voltage at higher temperatures and the venting gas that carries with it the products of electrolysis and water vapour.

Electrolyte specific gravity is also affected by temperature and needs to be adjusted accordingly depending on both specific gravity and temperature. Because a temperature-compensated specific gravity measurement requires a specific gravity and temperature measurement, the coefficient for that specific gravity is usually obtained from a table. For example, at a measured specific gravity of 1.300 at 0 °C, the specific gravity needs to be adjusted downward by 0.000738/°C to 1.282 to obtain a reading at 25 °C. At 40 °C, the same temperature-compensated specific gravity would read 1.271. Specific gravity tables can be obtained from the manufacturer's installation and operation manual.

Electrolyte stratification is caused when the heavier acid formed by the decomposition of sulfates on recharge migrates to the bottom of the battery and the lighter water/electrolyte mixture moves to the top of the battery. The non-uniformity in acid distribution causes unequal electrode utilization, reduced capacity, and premature electrode failure. If the gassing on recharge in vented batteries is limited by a low-regulation voltage or is cut short, then the required mixing of the electrolyte will not occur. Recovery requires extended heavy gassing of the battery for hours at voltages at or above 2.40 V per cell. Undersized PV arrays and/or low-regulation voltages are the major causes of battery stratification in PV systems.

In addition to the temperature effects, there are a number of other factors that need to be considered when measuring electrolyte-specific gravity. These factors include the state of charge of the battery, electrolyte water level, electrolyte stratification, and the cycle history of the battery. The most useful specific gravity data for a PV system are obtained just after a normal charge cycle when there has been a high solar resource period where the battery has recovered from any previous discharges. This measurement will provide an operational specific gravity, which should be near the manufacturers specified value for that battery. In cases where the electrolyte level is low, the measured value will be significantly higher than the specific gravity measured at a full electrolyte level. Manufacturers specify specific gravity at a full electrolyte level. All specific gravity measurements should be at the same water level to reduce measurement error. If specific gravity measurements are obtained at other than a high state of charge, then significant error can also be introduced as a result of stratification and sulfation.

C.4 Cycle-life

Lead-acid batteries designed for cycling applications usually have a manufacturer's rated cycle-life. The published cycle-life values are usually given at several different depths of discharge. The shallower the depth of discharge, the greater the cycle-life. It is important to understand that the rated cycle-life is usually measured under optimum conditions. If battery use is under less than optimum conditions, then the expected cycle-life may be less due to other battery degradation mechanisms. Cycle-life ratings for vented deep-cycle lead-antimony batteries range from less than 200 deep-cycles for light-duty batteries to over 1500 deep cycles at 80% DOD for heavy-duty industrial motive power batteries. The wear out mechanism is generally positive plate grid corrosion. The biggest difference between batteries with low and high cycle-life ratings is the positive plate grid thickness. Battery cost is usually proportional to grid thickness, cycle-life, and capacity.

The cycle-life of properly maintained and installed VRLA batteries is generally less than 300 deep-cycles for light-duty batteries and less than 1200 deep-cycles at 80% DOD for heavy duty industrial VRLA batteries. VRLA battery cycle-life is usually limited by water loss and grid corrosion, but other degradation mechanisms may also limit cycle-life.

C.5 Battery coulombic or ah recharge efficiency

Battery coulombic efficiency is usually measured using the discharged Ah divided by the charged Ah. Lead acid battery charge efficiency is affected by battery state of charge (SOC), battery design, battery grid alloy, charge rate, battery history, battery age, and cycle DOD. The charge efficiency for a discharged vented battery is initially about 99%, and as the battery approaches higher states-of charge, the efficiency will drop off and approach zero near 100 % SOC. There are significant efficiency differences between vented lead antimony and VRLA batteries. This is due to VRLA battery design and grid alloy. As a rough comparison, vented lead-antimony batteries will be about 80% efficient and VRLA batteries will be about 90 % to 95 % efficient for 100 % DOD cycles. This means that to recharge VRLA batteries requires about 105 % to 110 % more Ah and to recharge vented lead-antimony batteries requires about 120 % more Ah. Most of the efficiency improvement in VRLA batteries is due to the grid alloy and the immobilized electrolyte in conjunction with the valve-regulated vent caps, which facilitate the oxygen recombination process and eliminates the need to mix electrolyte.

Efficiency is lower for vented batteries because of the electrolyte stratification and the required electrolysis on charge. In addition to stratification and electrolysis, the battery history can make recharge considerably less efficient. If the battery is left in a discharged condition, then other battery degradation mechanisms such as "hard" sulfation and degradation of the positive active mass will result in a slower capacity recovery. To recover the lost capacity requires considerably more overcharge than the normal recharge and therefore lowers charge efficiency. The exact efficiency value for a specific SOC will vary considerably depending on the above factors. Therefore, PV array sizing needs to be increased to accommodate these efficiency losses so that the battery can recover from extended periods in a discharged condition.

C.6 Charge acceptance

Charge acceptance is a term used to describe the rate at which the battery can be recharged. Charge acceptance is also related to the "ampere-hour law", where the charging rate in amperes is kept below a value equal to the number of ampere-hours to be charged into the battery. Using the "ampere hour law" for recharge, the battery should not gas excessively or overheat. Charging vented batteries in excess of the charge acceptance limit will tend to result in secondary reactions such as electrolysis and will not reduce the time required to return the battery to 100 % SOC.

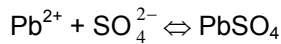
In PV systems, the charge rate is low, but the limited charge acceptance is still a factor when the battery reaches about 80 % to 90 % SOC. At this point, the charge current will usually be limited by the regulation voltage. Any excess current will only be used in electrolysis to gas the battery, which is needed for destratification of vented batteries. The charging current will continue to drop until the battery reaches 100 % SOC, and then only the electrolysis or gassing current will be left. The time required to achieve 100 % SOC would be an indication of charge acceptance and may be many hours. Another measure of charge acceptance is the number of Ah returned back to the battery within a fixed time period under a fixed voltage at a constant temperature. It is important to understand that in PV systems, it is necessary to ensure that there is an adequate PV array size to provide the battery with sufficient charge to recover from the previous discharge cycle.

C.7 Sulfation

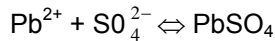
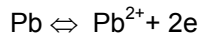
Sulfation is the normal result of battery discharge when lead-sulfate forms on the surface and in the pores of the active plate material [see Equation (C.2)].

Positive Plate





Negative Plate



Sulfation becomes a problem when large crystals of lead sulfate form on the active material as a result of inadequate charging and battery neglect or misuse. It is difficult, by charging, to decompose these large lead sulfate crystals in order to return their sulfate ions back to the electrolyte. This effectively reduces battery capacity and life. Large sulfate crystals may be detectable by a hard rough surface on the active plate material or a low specific gravity after an equalization charge. This is called excessive sulfation or "hard" sulfation. "Hard" sulfation is caused by some of the following form of abuse:

- Allowing the battery to stand in a discharged condition for an extended period of time
- Adding additional electrolyte to the battery cells instead of water.
- Operating the battery while consistently undercharging it

Temperature fluctuations while the battery is standing idle also play an important part in the growth of large sulfate crystals. When the temperature increases, the smaller sulfate crystals dissolve in the electrolyte, and when the temperature decreases, the sulfate solubility is lower and the crystals slowly grow larger again. The temperature swings promote the slow growth of large sulfate crystals that would otherwise be small and more easily dissolved into the electrolyte. An undersized PV array and/or low-regulation voltage will result in consistently undercharged batteries and "hard" sulfation in addition to other battery degradation processes.

C.8 Hydration

Hydration occurs when a lead-acid battery is over discharged and left in the discharged condition for an extended period of time. Hydration is formed when lead is dissolved into solution with the water in the electrolyte that results from over discharge. A hydrated battery will have a white film around and between the plates. This lead-hydrate film will inhibit charge, making the battery unrecoverable.

C.9 Mossing

Mossing can occur in vented cells where sloughed active positive material will circulate in the electrolyte and reform as negative material as it touches and adheres to the negative plate. A shorted cell may result when mossing occurs at the top of the cell and bridges its separators. This process is also referred to as treeing.

C.10 Battery mounting orientation

All vented batteries are required to be in the upright position, but VRLA batteries will operate in any position except upside down. The manufacturers of large industrial AGM VRLA batteries with plates over 0.4 m tall recommend that the battery be installed on its side. This reduces the height that electrolyte is required to wick up in the AGM and improves performance. Gel VRLA technology is unaffected by the mounting orientation.

C.11 Life-cycle considerations

To achieve the best cycle-life for a given application and battery requires the user to understand the battery design limitations, charge requirements, and maintenance requirements. Premature battery failures can generally be avoided by proper charge and/or installation and maintenance.

C.12 Battery thermal runaway

Under abnormal circumstances, battery thermal runaway can occur as a result of excessive charging at elevated temperatures. As the battery temperature increases, the electrolysis voltage drops, and this can result in excessive charge currents, which also increase the rate at which the internal battery heating occurs. As temperature control is an important consideration, any external heating such as that from direct sunlight should be avoided. Without proper charge control, which includes temperature-compensated regulation voltage, this process continues uncontrolled until the heat generated causes the plastic battery case to melt and vent, resulting in battery failure. Vented (flooded) batteries can dissipate heat much more effectively due to their excess liquid electrolyte, so the thermal runaway problem is predominately associated with VRLA batteries because of their limited ability to dissipate heat.

Annex D (informative)

PV system operational parameters

D.1 Battery charging

To prevent batteries in standalone PV systems from being undercharged, the charge regulation voltage must be set at the appropriate level, the PV array to load ratio must be sufficient, and/or the solar resource must be sufficient for the system design. Charging batteries is not simple and can be accomplished with many different charge profiles. As a rule of thumb, charging at a higher regulation voltage requires less time at regulation voltage and charging at a lower regulation voltage requires more time at regulation voltage. The time spent on charge below the regulation voltage is called the bulk-charge phase, and the time at regulation voltage is usually called the finish-charge or taper-charge or absorption phase of battery charging. PV systems operating during full sun periods may provide 2.5 h or less at regulation voltage every day, so most of the finish charge and, consequently, electrolyte mixing has to be done in that time period. The variations in the seasonal solar resource where the sun may be obscured during winter months or rainy seasons also need to be anticipated. In these low resource periods, the battery may not reach regulation voltage for weeks. This can seriously degrade the battery capacity even after an equalization charge.

The goal of battery charging is to return the battery to a high SOC each cycle to minimize the capacity degradation resulting from deficit-charge cycling. In addition to standard battery recharge, some battery applications will require an equalization or complete finish-charge at regular intervals to return the battery to 100 % SOC. Battery recharge is dependent on battery technology and the cycle profile. These two factors will determine how the battery should be charged. The battery charging parameters include regulation voltage, charge rate, time at regulation voltage, battery temperature, temperature-compensated regulation voltage, and equalization or finish-charge voltages and times. The charge algorithm is a critical element in the performance of the battery; therefore, every effort should be made to use an acceptable charge algorithm for the battery and application. The important consideration for PV systems is whether the system is capable of recovering lost battery capacity from low solar resource periods during average solar resource periods. If the time that the battery spends recovering from a discharge is excessive, then permanent capacity loss will result. The maximum safe recovery time is very dependent on the battery design.

D.2 Battery equalization

An equalizing charge is intended to correct any capacity, cell voltage, and/or specific gravity inequalities that may occur during service. It is a prolonged charge usually at an elevated voltage. The frequency of equalizing charge is dependent on the battery, charge algorithm, and cycle profile. Many manufacturers recommend an equalization charge every one to two weeks for daily use deep-cycle motive power industrial batteries. VRLA batteries may also require equalization charges and may or may not require an increase charge voltage. Equalizing VRLA batteries is recommended by the battery manufacturer when cell voltages become unbalanced or when the battery is left discharged for an extended time. A typical equalization charge for a VRLA battery may require 24 hours at the standard or slightly elevated regulation voltage (2.35 or 2.40 V per cell). Therefore, VRLA battery equalization in PV systems may not be practical.

Some PV charge controllers have a preset equalization-charge function that is triggered based on lapsed time or battery voltage. Others have a manually triggered equalization-charge function. When these functions are engaged, they generally boost the battery charging voltage for one day. The charge controller needs to reach the equalization voltage to complete the equalization charge. In most cases, the PV charge Controller equalization voltage is not as high, the time at equalization voltage is not as long, and the frequency of equalization charging is not as often as is recommended by the battery manufacturer. This is because of the limited charge current available with PV and the difficulty in using one equalization function for all PV systems and vented battery designs. Many PV systems may not be able to reach the normally high equalization voltage and spend the required time at

voltage for a complete equalization charge, but even if equalization is not complete, the additional charge can be beneficial.

D.3 PV array to load ratio

The PV array to load ratio (A:L) is the average daily PV ampere-hours or watt-hours available divided by the average daily load ampere-hours or watt-hours. The A:L ratio is a very important PV system design parameter because it determines if there are sufficient charge Ah or Wh to recharge the battery during average solar resource periods. In low resource periods, the A:L ratio can be insufficient to charge the battery, and in high resource periods, it can result in excessive battery charging. An average daily A:L ratio of 1.3 for Ah or 1.4 for Wh can maintain the PV battery regulation voltage for about two to three hours every day. Some batteries may suffer permanent capacity loss as a result of the low A:L ratio during low resource periods. If battery performance problems arise after extended low resource periods, then battery recovery can be improved by increasing the A:L ratio.

D.4 Charge controllers

PV charge controllers are designed to prevent excessive battery charging. In addition to charge control, PV charge controllers may include equalization charge control functions, a LVD, a load control relay, a battery status indicator, a backup engine generator charge control relay, a PV power diverter to auxiliary load, and a wiring center. PV charge controllers will use one of three basic charge control methods, which are on/off, pulse width modulated (PWM), and constant voltage. All the above charge control methods will work well with vented batteries, but it is important to use the right regulation voltage for the battery and system design. Typically, VRLA batteries are more easily charged with PWM and constant voltage charge control. This is because of the difficulty in obtaining the correct time interval between the high-voltage disconnect and reconnect for on/off controllers. Rapid on/off cycling can cause the charge controller to malfunction if the reconnect voltage is too high or undercharge the battery if the reconnect voltage is too low. Usually, battery manufacturers do not provide recommended on/off set points, so determining the right set points can require some testing if the PV system has higher or lower than normal charge rates or has loads that operate while the PV is charging the battery. Generally, battery manufacturers do provide recommended constant voltage set points, which are also the same as PWM set points.

D.5 V_r set point

The V_r set point is the maximum voltage that a charge controller will allow the battery to reach under charging conditions. At this point, the charge controller will either discontinue charging or begin to taper the charging current to the battery. Most battery manufacturers will recommend constant voltage set points for charging their batteries in cycling applications. With vented lead-antimony batteries, there is considerable flexibility with respect to V_r set point. V_r set point values for constant voltage charging from 2.40 V per cell to 2.45 V per cell are common and in special cases can be set up to 2.55 V per cell depending on system and battery design. Higher regulation voltages will increase available capacity but increase water loss. VRLA battery designs require very precise voltage regulation at the battery manufacturer's recommended V_r set point. VRLA set points of 2.35 V per cell or 2.40 V per cell for cycle charging applications are most common. Increasing the regulation voltage above the manufacturer's recommended value may shorten the cycle-life of VRLA batteries due to an increased likelihood for venting and water loss.

On/off controllers require two set point voltages, the array disconnect (V_r) and the reconnect voltage (V_{rr}). In most stand-alone PV systems using vented lead-antimony batteries, the array disconnect voltage should be between 2.45 and 2.50 V per cell and the array reconnect should be about 2.28 V per cell. The choice of the array reconnect voltage is dependent on the load profile and the switching speed of the PV charge controller. If there is a load current when the PV array reaches the disconnect voltage, then the reconnect voltage may be lowered to accommodate the rapid drop in battery voltage under load.

Most battery manufacturers do not recommend on/off charging for VRLA batteries, but many PV systems have successfully used on/off controllers if set points are appropriate. The key to successful implementation of an on/off VRLA charge controller is to set the array disconnect to about 0.02 to 0.05 V per cell higher than the recommended constant voltage regulation voltage and set the

reconnect voltage to about 2.28 V per cell. For larger systems, on/off staged PV array shedding is quite effective in providing a taper charge for VRLA batteries. Table D.1 provides possible PV charge controller set points for VRLA, vented lead calcium, and vented lead-antimony batteries.

Table D.1 — Default PV battery charge controller regulation voltages at 25 °C

Variable	Vented, lead antimony ^a	Vented, lead calcium ^a	VRLA, AGM ^a	VRLA, Gel ^a
V_r , set point, V per cell (Constant voltage or PWM)	2.40 to 2.50	2.45 to 2.55	2.35	2.35 to 2.40
V_i , set point, V per cell (on/off disconnect)	2.45 to 2.50	2.50 to 2.55	2.40 to 2.42	2.40 to 2.42
V_{rr} , set point, V per cell (on/off reconnect)	2.25 to 2.28	2.25 to 2.28	2.25 to 2.28	2.25 to 2.28
LVD, V per cell	1.90 to 2.00	1.90 to 2.00	1.90 to 2.00	1.90 to 2.00
LVR, V per cell	2.17 to 2.25	2.18 to 2.25	2.18 to 2.25	2.18 to 2.25
* This value has to be within the system's operating voltage limits.				

D.6 Maximum system voltage

Many PV battery systems are nominally 48 V or less. Higher voltage battery banks are routinely installed and used successfully, but special care must be taken with these higher voltage battery systems to prevent cell imbalances, ground faults, and ensure electrical safety.

As the number of series cells in a battery increases (e.g. battery strings over 48 V), it becomes increasingly easier for individual cells to become charge unbalanced. As a consequence, the battery's cells can be at various states of charge, which will be reflected by cells having various voltages and available capacities. If not corrected, any unbalanced condition will continue to degrade with subsequent cycles, resulting in increasingly greater variation in cell voltages and, more importantly; cell available capacities. In any case, the battery manufacturer should be consulted for corrective action. One bad cell can damage the entire battery bank. To prevent this requires cell voltage monitoring at regular intervals and appropriate action when a bad cell is identified. There are a number of probable causes for battery string cell imbalances that could include a weak cell, high-resistance connection, and consistent undercharging. If repair of the connection and/or an equalization charge does not recover the cell, then cell replacement is possible in some cases where the battery string is relatively new.

Electrical safety at higher battery voltages requires electrically shielding all exposed battery terminals and using electrical disconnects, fuses, and circuit breakers rated for the maximum DC battery voltage in accordance with KS 662.

D.7 Ground faults

The higher the battery voltage, the more impact existing battery string ground faults have on the system. Ground faults can result in battery fires and explosions due to the electrical heating of a current path to ground. Preventing ground faults requires good battery installation and maintenance practices. Battery maintenance includes the following:

- Removing corrosion and electrolyte vapor deposits on the top surface of the battery
- Ensuring that there are no conductive surfaces to ground near the terminals
- Using nonconductive battery trays or cases, particularly for systems over 48 V
- Using appropriate battery vent caps with flame arresters to minimize the possibility of fire and/or explosions

Ensuring adequate standoff or separation between battery terminals and grounded support structures is critical. Electrolyte mist will deposit on battery surfaces, reducing the electrical resistance to ground. If electrically conductive and grounded battery trays are used with vented cells, then the possibility of

ground faults is greatly increased. Conductive cases are prohibited for vented lead-acid battery systems operating above a nominal 48 V (24, 2 V cells). Conductive racks may be used for these systems provided no rack material is within 150 mm of the tops of the cells.

For VRLA batteries, the conductive electrolyte is well contained within the battery and usually does not form on the battery surface. The improved electrolyte containment allows VRLA batteries to be used in conductive trays or racks over 48 V. VRLA batteries do leak electrolyte on occasion, so every effort should be made to keep these batteries clean and minimize electrically conductive support structures near the battery terminals. In many higher voltage battery banks, ground fault detection equipment is an important safety feature that can warn personnel when excessive leakage currents are occurring and a ground fault is pending.

D.8 Depth of discharge

Depth of discharge (DOD) is the percentage of discharged Ah per cycle relative to rated battery capacity. Most applications only cycle the battery to a maximum of 80 % DOD or less. PV systems will usually cycle the batteries daily between 10 % and 20 %, but in low solar resource periods, the battery may cycle to the LVD. LVD is usually set between 1.9 V per cell and 2.0 V per cell for discharge rates higher than the 35 h rate. The above LVD set points will discharge the battery between 50% and 95% DOD. It is also important to adjust the LVD voltage upward to prevent over discharge if discharge rates are much lower.

D.9 Temperature effects

PV systems are installed all around the world in hot and cold climates, and as a result of these climate variations, batteries in these systems need to be cared for appropriately. It is unlikely that PV batteries will be installed in systems where there is extra power for heating and air conditioning, so some battery temperature extremes are unavoidable. If the battery temperature deviates from 25 °C significantly, temperature-compensated regulation voltage is a recommended feature of the PV charge controller. Additional cost-effective measures for battery temperature management include insulating the battery enclosure, partially or completely burying the battery enclosure, and ensuring that the battery or enclosure is not exposed to direct sunlight or cold drafts. It is also important to understand that VRLA batteries are much more sensitive to temperatures over 25 °C. Many times just using a more heat-tolerant battery such as a vented lead-antimony battery is a good solution to the potential cycle-life limiting effects of higher operating temperatures on VRLA batteries. Vented lead-acid batteries can be operated at temperatures between -10 °C and 40 °C, but every effort should be made to maintain battery temperature near 25 °C when possible. This prevents freezing of the electrolyte, excessive grid corrosion and improves performance. VRLA batteries, on the other hand, are much more tolerant to cold temperatures because if the electrolyte freezes, it is unlikely to crack the battery case, but at temperatures near 35 °C, VRLA batteries are near their recommended high temperature limit.

D.10 Autonomy

Autonomy is the number of days a PV battery will carry the load without energy from the PV array. The number of days of autonomy is a function of the acceptable loss of load probability and the weather patterns. Although many stand-alone PV systems are designed with five days of autonomy, some critical load systems (e.g., telecommunication) feature batteries with ten or more days of autonomy. Typical autonomies range from 5 to 25 days. Several factors go into this design guideline, including the length of typical cloudy periods and the practical limits for system component sizing. Low insolation days in locations where PV is used will usually last less than five days. Excessive autonomy can make it difficult to charge the battery and can increase system cost with an oversized battery.

D.11 Geographical site location

Geographical site location issues generally include weather patterns, minimum and maximum temperatures, and earthquake zones. If the weather patterns are such that there are seasonal patterns of low solar resource, then the load may have to be disconnected or greatly reduced during that time period. In very cold or very hot climates, the batteries should be insulated or installed

underground to protect them from extreme temperatures. In earthquake zones, the batteries need adequate support as required by the local building codes.

D.12 PV battery end-of-life

In stationary float service applications, battery end-of life is generally defined when battery capacity drops to less than 80 % of its rated value. If this requirement was applied to standalone PV systems, many batteries would be at end-of life shortly after installation. End-of life for PV batteries is not well defined. In most stand-alone PV applications, the battery end-of life is defined when the battery fails to meet the daily loads of the system during good solar resource periods. Battery failure can be due to undercharging, excessive loads, system component failures, or normal battery wears out. Excessive loads and/or system component failures will usually result in undercharged batteries with associated capacity loss. If the battery is continually undercharged, then "hard" sulfation, stratification, negative plate grid loss, and other degradation mechanisms in the positive active mass will result in permanent premature capacity losses. Battery recovery after continued under charging may or may not be possible by equalization. Normal wear out also results in capacity loss from the traditional mechanisms of positive grid corrosion and positive active material shedding. When this occurs, the battery can experience excessive positive plate growth or bulging and cell shorting.

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